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THE USE OF OILS FOR REDUCING HEAVY SEAS

S. V. Dobroklonskiy, V. A. Tyumeneva
Marine Hydrophysics Inst, Acad Sci USSR
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/Figures referred to are appended./

Seamen have long known that heavy seas can be calmed by pouring oil onto the waves; however, the mechanism of this phenomenon has remained obscure until recently. Quantitative measurements of this action were made first by R. N. Ivanov (Izv. AN SSSR, Ser. Geograf. i Geofiz., No 3, pp 325-343, 1937; ibid., No 1, 29, 1938), who proved by a very refined method that the action of oily substances was in no way connected with any decrease of surface tension between air and water (as was supposed in some hypotheses). Therefore, the damping action was due to some sort of irreversible process caused by the presence of oil films.

According to V. V. Shuleykin's hypothesis (Izv. AN SSSR, Ser. Geograf. i Geofiz., No 3, pp 345-355, 1937; Physics of the Sea, Izd. AN SSSR, Moscow-Leningrad, p. 671, 1941), this irreversible process must take place in the film itself, the molecules of which are forced first to depart from the surface in favor of the deeper rows when the water surface contracts on the crest of the wave and then to rise again to the surface when the surface layer expands in the wave trough. The larger and "more branched" the complex molecules of fatty acids, the more energy should be absorbed in this process by internal friction in the damping film.

Ivanov forced thin water films covered on two sides with layers of salts of fatty acids to alternately expand and contract, i.e., soap films were stretched in a special instrument between a hair registering the deformation force and a rack oscillating exponentially. He obtained real "hysteresis loops" for films of various surface-active substances and determined the amount of energy absorbed in expansion and contraction of such films.

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Knowing these experimental constants of Ivanov and knowing the laws of contraction and expansion of the wave surface, Shuleykin calculated the amount of energy which should be removed from waves by films of oily surface-active substances. It turned out that for waves with low period (i.e., for steep, dangerous waves), the energy absorbed was greater than that given the wave by the wind.

Despite the accuracy and conclusiveness of Ivanov's experiments, Levich (Levich, V. G., The Theory of Surface Effects, Izd. "Sovetskaya Nauka," 1941) later published a mathematical work which represented a return to the old, purely formalistic theory of Lamb (Lamb, G., Hydrodynamics, Translation from the 6th English edition, 1932, GTTI, Moscow-Leningrad, 1947) on the mechanism of damping by oil films. This theory proposes that the wave energy must be damped simply because of the presence of foreign molecules on the water surface, these foreign molecules forming some sort of rigid boundary on the water. This "rigid" boundary, it seems, must change the kinematics of the wave motion of the liquid in comparison with the "free" wave and thus increase viscous friction losses in the medium. Both Lamb and Levich, however, were drawn off from the physical effects which must occur in the surface film of foreign molecules and therefore the Levich-Lamb hypothesis could not explain the considerable difference in the damping capabilities of films of mineral, vegetable, and animal derivation. On the other hand, the damping effect of the "rigid boundary" is very much in the background in comparison with the effect of viscosity of the film substance itself (according to Shuleykin-Ivanov) at frequencies fairly close to the natural one.

This work has the twofold aim of investigating the damping action of surface-active substances directly on waves (and not on isolated Ivanov films) and revealing the inconsistency of the formalistic Levich-Lamb hypothesis.

The test unit which we constructed for the study consisted of a tank with water, a wave producer, and an optical sounding unit which permitted us to measure the relative heights of waves at different points of the tank. The speed of the wave producer motor could be varied from 15 to 60 revolutions per second.

This unit was used to study attentuation of waves of various frequencies on a water surface which was covered with monomolecular films of oleic acid, fish oil, and lauric acid.

Table 1 shows the results of measurements of frequencies, wave lengths, and coefficients of wave damping for the substances studied, and also the calculated values of the theoretical coefficients of damping and the damping constant. As the "theoretical" damping coefficients, we have: B_p, corresponding to total absorption of energy in a viscous liquid for free wave motion and separately in the film in correspondence with the Shuleykin-Ivanov hypothesis; B_1, which gives the wave damping due solely to the internal viscosity of the liquid, and B_{zh}, which characterizes the absorption of energy by viscosity forces when the wave according to Lamb is "nonfree" because of the presence of a rigid film on the surface.

The damping constants found from theoretical formulas are shown in column 6 of the table, which also gives the average values for each substance. It is interesting to note that the value of a for oleic acid (0.0102 erg·sec/sq cm) is almost 150 times less than that obtained by Ivanov from experiments on soap films for 0.01 normal sodium oleate (1.49 erg·sec/sq cm).

Table 1. Experimental and Theoretical Values of Damping Coefficients For Frequency Interval From 16 to 60 Cycles

Substance	Measured Frequency f (Cycles)	Measured Wave Length (cm)	Measured Damping Coefficients B (per cm)	B_p With Average Value of a (per cm)	Damping Constant a (erg· sec) sq cm)	B_1 per cm	B_{zh} per cm
Oleic acid	16.2	1.15	0.087	0.088	0.0098	0.043	0.122
	27.1	0.72	0.222	0.229	0.0097	0.085	0.196
	44.4	0.53	0.404	0.383	0.0110	0.116	0.252
	55.2	0.48	0.431	0.431	0.0102	0.122	0.267
					$\bar{a}$ = 0.0102 (average)		
Fish oil	21.8	0.89	0.134	0.142	0.0093	0.060	0.152
	28.0	0.71	0.248	0.231	0.0114	0.085	0.196
	40.3	0.55	0.369	0.376	0.0099	0.116	0.250
					$\bar{a}$ = 0.0102 (average)		
Lauric acid	25.8	0.87	0.079	0.086	0.0043	0.049	0.138
	30.9	0.73	0.125	0.127	0.0052	0.067	0.164
	39.0	0.73	0.192	0.180	0.0060	0.088	0.195
	51.5	0.52	0.242	0.220	0.0058	0.103	0.247
					$\bar{a}$ = 0.0053 (average)		

The difference in values is possibly caused by the fact that we used pure fatty acids in our experiments while Ivanov used the salts of the fatty acids; the strong polarity of . e alkaline elements entering into these salts undoubtedly plays a very important role. The fact that similar strongly polar molecules can rapidly form when even pure fatty acids come in contact with sodium ions, abundantly present in sea water, is very important for practice.

The individual numbers of column 6 show that the values a for oleic acid and fish oil do not reveal any systematic behavior with increasing frequency, while the damping constant for lauric acid increases almost continuously for the frequencies considered, giving the highest mean square error (12.6%) of all the substances. This result gives us reason to believe that the first two substances follow the Shuleykin-Ivanov hypothesis quite satisfactorily, while the last is somewhat poorer.

Figures 1, 2, and 3 show the behavior of the theoretical damping coefficients B_p, B_1, and B_{zh} with frequency. The measured values of B are encircled. The graphs show that the experimental points for all the substances are close to the curve corresponding to the coefficient B_p, while they are quite far removed from the curves for B_1 and B_{zh}. A slight exception is the region of frequencies above 30 cycles for lauric acid. Undoubtedly, we are dealing here with processes which have nothing in common with those which exist in nature on the surface of waves covered by oily substances which produce true surface solutions. We separated lauric acid from a gasoline solution ("molecular lacquer"), and therefore the inability of its molecules to move from layer to layer during the passage of crests and troughs of waves became noticeable at the comparatively higher frequencies.

Thus, comparison of experimental data with theoretical permits us to draw the following conclusions:

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1. The behavior of the observed damping coefficient of waves for films of the substances studied in the region of 15-60 cycles is satisfactorily explained by the Ivanov-Shuleykin theory; the waves are damping mainly by irreversible processes in the film of surface-active substances.

2. The "rigid boundary" on the wave surface adopted by the Levich-Lamb theory produces only a minor effect which is not capable of damping waves under natural conditions.

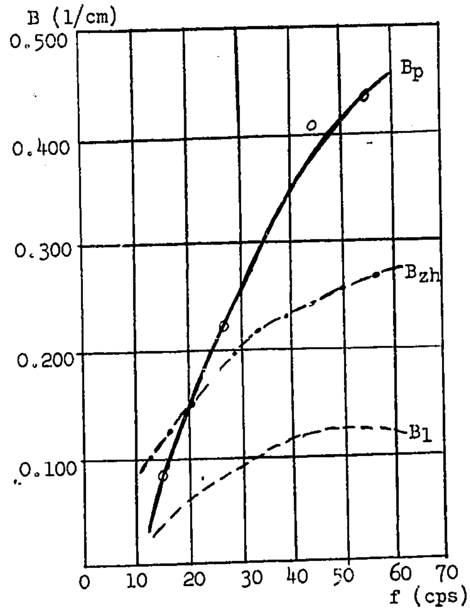

Figure 1. Coefficients Found From Experiments of Wave Damping on a Water Surface Covered With a Film of Oleic Acid as a Function of Frequency and Theoretical Damping Coefficients

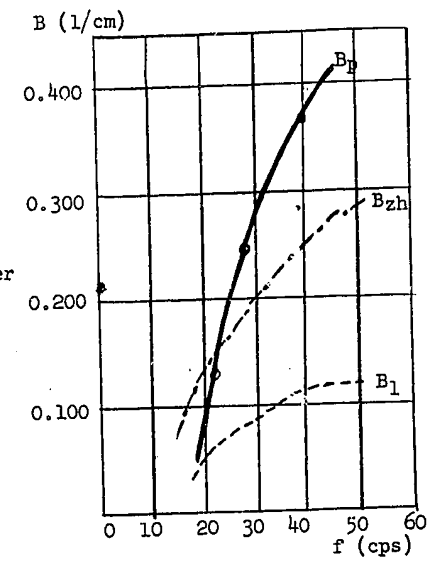

Figure 2. Coefficients Found From Experiments of Wave Damping on a Water Surface Covered With a Film of Fish Oil As a Function of Frequency and Theoretical Damping Coefficients

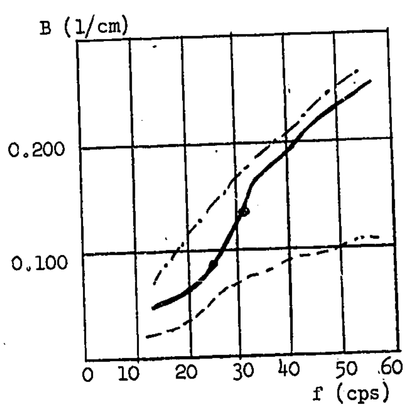

Figure 3. Coefficients Found From Experiments of Wave Damping on a Water Surface Covered With a Film of Lauric Acid as a Function of Frequency and Theoretical Damping Coefficients

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